Inversion for Geoacoustic Model Parameters in Range-Dependent Shallow Water Environments

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LONG TERM GOALS

Our ability to predict acoustic fields in shallow water is limited by knowledge of the parameters of geoacoustic models that are used to describe the interaction with the ocean bottom. The long-term goal of this research is to investigate broadband matched field inversion methods for estimating geoacoustic model parameters and their uncertainties in shallow water environments that may be range dependent.

OBJECTIVES

Inversion for geoacoustic model parameters is set within the wider context of research to investigate the effect of the ocean bottom on sound propagation. The need for information about geoacoustic model parameters is critical for shallow water and littoral environments where the interaction with the ocean bottom plays a dominant role in sound propagation. Results from the 2001 SPAWAR/ONR benchmark workshop to assess the performance limits of present day inversion techniques for range-dependent shallow water environments have demonstrated that there are several methods in use today that can provide accurate approximations for sound speed profiles in the bottom (Chapman et al., 2003, 2004). Our objective is to test the performance of new model-based (matched field) inversion methods developed in the workshop on experimental data. The methods will be applied to data from the South Florida Ocean Measurement Centre (SFOMC) in order to estimate geoacoustic model parameters for the bottom at the SFOMC site.

APPROACH

The research described here made use of data obtained in a recent experiment carried out at the SFOMC site to investigate acoustic propagation at the site (Nguyen et al., IEEE JOE, 27, 235-244, 2002). In the experiment, M-sequence signals in the frequency band 100-3200 Hz were transmitted from a source at 10 km range to a 32-element vertical line array for a period of about 20 days. The signal transmission was parallel to the contour of the continental shelf at about 155 m water depth. Preliminary analysis of the propagation characteristics of the waveguide suggested stable propagation channels for primarily water column signals with multiple bottom and sea surface interactions, and for refracted signals that interact with the bottom at low grazing angles (Monjo and DeFerrari, JASA, 95, 3129-3148, 1994). Our focus was the low frequency data (< 200 Hz) that showed a strong secondary signal which followed the strong first arrival by about 0.4 s.

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14. ABSTRACT
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Initial attempts to invert the data by conventional matched field inversion assumed that the secondary arrival was associated with interaction in the subbottom. However, the inversions failed to generate a realistic geoacoustic model that could correctly reproduce the arrival structure, particularly the secondary arrival. A more detailed study of the environment in the vicinity of the experimental site revealed a complex bathymetry consisting of a steep gradient slope shoreward of the site running parallel to the direction of signal propagation in the source receiver plane (Figure 1). In order to understand nature of signal propagation in this complicated sloping bottom environment, the array data were processed using a time delay beamformer that was designed for the sparse, unevenly spaced vertical line array. The amplitude shading factors for each beam were determined in a nonlinear inverse process that optimized the ratio of main beam level to sidelobe level.

The vertical signal directionality for the 100 Hz data is shown in Figure 2. The first arrival consists of components with vertical propagation angles from 3-4º to around 20º, whereas the second arrival consists of only steeper angle components. Based on these results, we hypothesize the following model for sound propagation. The steep slope effectively creates a 'wall' that can return acoustic energy to deeper waters by horizontal refraction of bottom interacting acoustic waves. Our model of sound propagation assumes that the first arrival is due to sound energy propagated in the plane of the source and receiver, whereas the second arrival is horizontally refracted by the wall.

Our approach for the inversion is designed to account for the three dimensional sound propagation at the site. The method is based on matched beam processing to spatially filter the array data into its vertical propagation angles. By selecting only the low angle beams < 6º, the second arrival can be eliminated. The inversion algorithm matches the beam time series for the shallow angle beams, assuming that the signal propagation at shallow angles is in the plane of the source and receiver. This allows the use of a two dimensional propagation model for calculating the replica fields at the array. The hybrid search method, Adaptive Simplex Simulated Annealing (ASSA), was used for navigating the model parameter space (Musil, Wilmut, and Chapman IEEE JOE, 24, 358-369, 1999; Dosso, Wilmut and Lapinski, IEEE JOE, 26, 324-336, 2001).

WORK COMPLETED

Acoustic data were received from Dr. DeFerrari in the form of unprocessed pressure signals at the array for the M-sequence sound transmissions from 100–3200 Hz for the entire experimental period. Environmental data consisting of the complete record of sound velocity profiles that were taken in the experiment, and information about the experimental geometry were also supplied. For the inversion of the 100 and 200-Hz data, we assumed that the waveguide was range independent, and used the normal mode propagation model ORCA to construct the signal fields. Matched beam inversions were carried out for both frequencies.

RESULTS

The long-range experimental geometry presented a significant challenge for MF inversion methods that rely on information in the spatial or temporal coherence of the signal. For the inversions reported here, we have made the simple assumption that the geoacoustic model is range independent; consequently, we expect that the estimated profile represents an average of the true environment over the 10–km propagation path. The inversion estimated three geometric parameters and five geoacoustic parameters of a two-layer sediment model.

The results for the sensitive model parameters, including the sound speed, density and attenuation of the sea floor, are shown in Table 1 that lists the averaged estimates for about 20 inversions at each frequency. Information about the properties of the second layer is less well defined, and sensitivity to the shear properties is generally low.

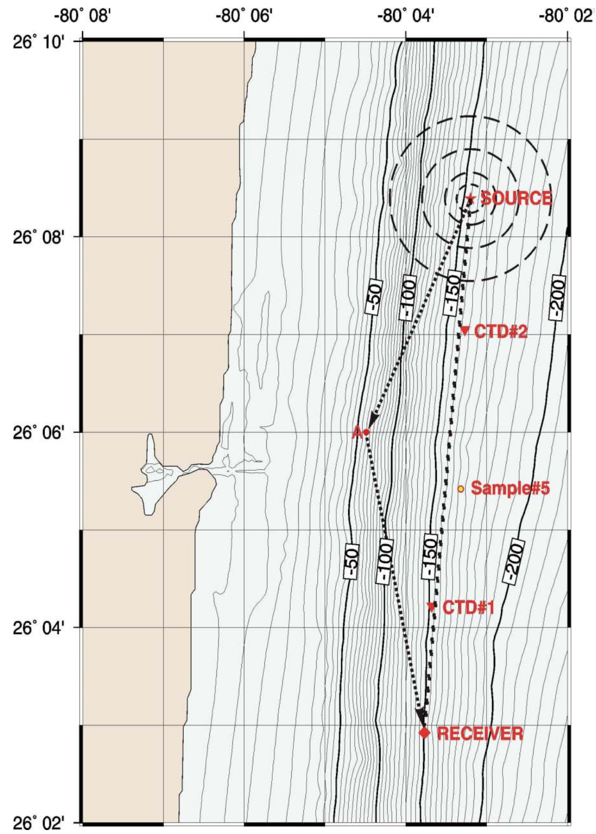

Figure 1. Location of the experiment and signal propagation paths. The dotted line shows the horizontally refracted component from the steep gradient 'wall'.

The estimated values for the geoacoustic parameters are in very good agreement with data from a sediment core mid way along the propagation path. The geometrical parameters are in excellent agreement with independent measurements of the experimental arrangement taken during the experiment. These results suggest that the approach used in the inversion to spatially select only the shallow angle propagation components of the signal was successful in eliminating the out-of-plane signal in the second arrival. Consequently, the inversion could be carried out using a 2-dimensional propagation model to calculate replica fields for the shallow-angle signal components propagating in the plane of the source and receiver. In addition, the approach allows the use of data from the entire array in the inversion.

Table 1. Results of inversions.

Frequency	cp1 (m/s)	cs1 (m/s)	αp1 (dB/m)	ρ1 (g/m^3)	Range (km)	Water Depth (m)	Source Depth (m)
100 Hz	1683	250	0.0013	1.79	10.09	153.7	107
200 Hz	1686		0.123	1.52	10.06	153.3	110
'True' values	1676			1.78	10.14	155	107/112

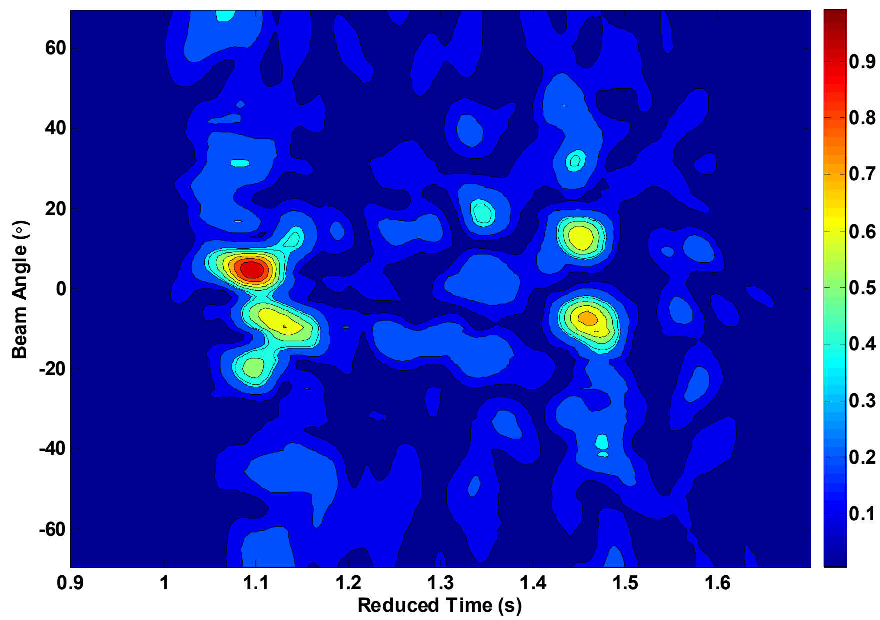

Figure 2. Vertical directionality of the signal at 100 Hz. The second arrival consists of only higher angle propagation paths.

IMPACT/APPLICATIONS

The project demonstrated several issues connected with the design of experiments for investigating the interaction with the ocean bottom and for inversion of geoacoustic model parameters. The lessons learned have been applied in the workshop sessions leading up to the design of the ONR Shallow Water experiment:

- The long-range experimental geometry provides sensitivity for estimating attenuation, and possibly shear speed, by inversion of acoustic field data.

- However, in order to make effective use of the long-range data, it is necessary to know ground truth along the propagation path, and make measurements of the acoustic field at intermediate ranges to determine the range dependence of the geoacoustic model.

- The broadband M-sequence signal transmissions provide good quality data for use in geoacoustic inversion.

- An inversion based on matched beam processing provides the advantage of selecting specific components of the signal by spatially filtering specific beams.

The project provided the opportunity to evaluate some of the approaches that were developed in the ONR-sponsored geoacoustic benchmark workshop against real data, an issue that was recognized as the next step in the geoacoustic inversion benchmark process.

The most significant feature from this work is the demonstration that three dimensional propagation in the cross-slope propagation geometry has an important impact on sound propagation, and hence on matched field inversion, at the site. It is believed that this issue will have significant implications for data processing for future experiments at the SFOMC.

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PUBLICATIONS

Chapman, N.R., S. Chin-Bing, D. King and R.B. Evans, Guest Editorial: Special Issue on Geoacoustic Inversion in range-dependent shallow water environments, IEEE Journal Oceanic Eng., 28, 318-320, 2003 (reviewed).

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HONORS

N.R. Chapman was elected Chair of the Technical Committee on Acoustical Oceanography of the Acoustical Society of America, 2004-2007.

The paper ‘Benchmarking geoacoustic inversion methods for range-dependent waveguides’ in IEEE Journal Oceanic Eng. was determined by Thomson ISI as one of the most cited recent papers in the field of Engineering, May 2004